Chapter 12. Future Upgrade

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The baseline design of the PD2 synchrotron provides 0.5 MW proton beams at 8 GeV. Chapters 1 through 11 are a detailed description of the PD2 synchrotron design concepts and technical components. A possible siting within Fermilab is identified. The design and the choice of the site also provide the potential to upgrade the beam power to 2 MW in the future. This can be achieved by a further increase in the linac energy from 600 MeV to 1.9 GeV.

Beam power is the product of beam energy E, number of protons per cycle N, and repetition rate f_{rep}:

$$P_{beam} = E \times N \times f_{rep}$$

Because the peak dipole field in the PD2 design is 1.5 Tesla, it would be difficult to increase the beam energy above 8 GeV. The 15 Hz repetition rate would also be difficult to increase because of eddy current losses in the laminations and coils of the magnets. Therefore, in order to raise the beam power, a logical step is to increase the number of protons per cycle.

Space charge is a major concern in high intensity proton machines. The effect scales as $\beta\gamma^2$, the relativistic factor. When the linac energy is increased from 600 MeV to 1.9 GeV, this scaling factor increases by a factor of 4. Therefore, for the same space charge effect, the beam intensity can be increased by a factor of 4. The number of protons per bunch increases from 3×10^{11} to 1.2×10^{12} and the number of protons per cycle increases from 2.5×10^{13} to 1×10^{14}. Consequently, the beam power increases from 0.5 MW to 2 MW. Table 12.1 lists these parameters.

Table 12.1. Parameters of PD2 Upgrade

Parameters	PD2 Baseline	PD2 Upgrade
Linac energy (MeV)	600	1900
Synchrotron peak energy (GeV)	8	8
Protons per cycle	2.5×10^{13}	1×10^{14}
Protons per bunch	3×10^{11}	1.2×10^{12}
Repetition rate (Hz)	15	15
Beam power (MW)	0.5	2

In the PD2 design, the 600-MeV beam transport line is about 254-m long. This leaves enough room for another 1.3 GeV accelerating structure to bring the linac energy up to 1.9 GeV. When one takes this upgrade path, one should consider using superconducting (sc) rf cavities for the additional 1.3 GeV acceleration. This technology is making rapid progresses thanks to the SNS Project and R&D work at other labs (DESY, CERN, CEA/Saclay, ANL, JLab, etc.). Compared to room temperature rf linacs (e.g., the 800 MeV linac at LANL), sc rf linacs have higher accelerating gradient and probably also cost less. One issue that needs to be addressed when adopting an sc linac is the proton beam pulse length. An sc linac works well for long pulses (1 msec or longer). Whether it is an appropriate choice for short pulse operations (e.g., 360 μsec in the PD2 upgrade) need further investigations.

In the PD2 upgrade, the existing normal conducting CCL rf system will be reused, because this is a relatively new system in the Fermilab accelerator complex, built about 10 years ago. However, the pulse length of this system must be raised. When the beam intensity is increased by a factor of 4, the number of protons injected from the linac also increases by the same factor. Assuming the linac peak current remains the same as in the PD2 design (50 mA), the pulse length needs to be quadrupled, from 90 μsec to 360 μsec. The existing CCL structures (from 110 MeV to 400 MeV) can only give a maximum pulse length of about 100 μsec (see Ch. 8). These structures need to be modified. Although the klystrons may be able to operate at longer pulses, the modulators and pulse transformers must be replaced. Moreover, the CCL cavity-sparking rate has a strong dependence on the pulse length. This also needs to be studied.